

40 YEARS OF SEAWATER DESALINATION AT GUANTANAMO BAY, CUBA

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Introduction

In February 1964, when the Cuban government cut off the water supply to the US Naval Base at Guantanamo Bay, the water use of 10,000 Naval and civilian personnel was limited to only fresh water shipped from the US mainland. To increase the Base water supplies as quickly as possible, the Navy entered an agreement with the Department of the Interior, Office of Saline Water (OSW) to relocate the 1 MGD demonstration multiple stage flash (MSF) desalination unit from Point Loma, California to Guantanamo Bay.

At that time, Burns and Roe had been operating the Point Loma unit successfully for demonstration and research purposes for over two years. During the Cuban crisis, Burns and Roe, under contract to Westinghouse, was responsible for dismantling, shipping, redesigning, and reconstructing the plant at Guantanamo Bay. As part of the research program, the Point Loma evaporator had 8 stages of carbon steel tubes, 90-10 copper nickel tubes in the remaining heat recovery stages and aluminum brass tubes in the two reject stages. At the time of dismantling of the plant Point Loma, the steel tubing had deteriorated to such an extent that these stages were scrapped and not relocated to Guantanamo Bay. Thus, the number of stages was reduced from 36 to 28. This resulted in a new evaporator design rating of 750,000 GPD. Within five months, the desalination unit went on stream to produce fresh water. This was the beginning of four decades of seawater desalination in Guantanamo Bay.

In order to eliminate shipping of fresh water from the US mainland and to provide adequate water supply to the Base, two other Westinghouse MSF units, each rated at 750,000 GPD were added within a year to bring a total capacity to the Base of 2.25 GPD. In 1979, one 750,000 GPD Aqua Chem MSF long tube evaporator was added to meet increased base water requirements. In 1988, the Point Loma Evaporator was decommissioned and replaced by two 1 MGD IDE multiple effect falling film horizontal tube evaporators. By 2002, all the MSF units were dismantled and the ME units were decommissioned.

In 1990, after GTMO 1 & 2 evaporators were dismantled, two RO units from Aqua Design, each rated at 300,000 GPD, were installed to replace them. The successful operation of the first two RO units led to a plan to replace all the thermal units with RO units. The Base is now operating with six seawater RO units.

This paper presents the operation and maintenance experience and improvements made for both thermal and RO desalination units to ensure adequate water supply is provided to the Base.

Thermal Desalination Units

The thermal units in Guantanamo Bay include four multiple stage flash evaporator units and two multiple effect evaporator units. Power supply to these units is steam turbine generators. Table 1 shows the thermal units installed in Guantanamo Bay.

Table 1 – Guantanamo Bay Seawater Thermal Desalination Units				
	Year	Type	Manufacturer	Capacity
Point Loma	1964	MSF – Recycle	Westinghouse	0.75 MGD
GTMO No. 1	1965	MSF – Recycle	Westinghouse	0.75 MGD
GTMO No. 2	1965	MSF – Recycle	Westinghouse	0.75 MGD
GTMO No. 3	1979	MSF – Once-thru	Aqua Chem	0.75 MGD
GTMO No. 4	1988	ME – Falling film	IDE	1.00 MGD
GTMO No. 5	1988	ME – Falling film	IDE	1.00 MGD

Point Loma, GTMO No.1 and No.2

All distillation processes make use of the physical fact that when water is heated in a vessel where the pressure is equal to its vapor pressure, the water will boil and vapor will be produced. Boiling can occur at any seawater temperature depending on whether the vessel is pressurized or under vacuum.

The MSF recycle process is one of the most successful distillation processes to date. MSF process makes use of the fact that water boils at lower and lower temperature as the pressure is reduced. The major plant components are the heat recovery evaporator stages and condenser bundles, the heat rejection section, the brine heater, the recycle pump and deaerator. The stages are generally numbered with the first stage at the hot end of the plant. Raw seawater enters the cold end of the heat rejection evaporator stages and withdrawn after passing 3 (or 4) stages. A portion of the withdrawn raw seawater from the heat rejection stages is used as makeup and is deaerated. This then mixes with the recycle stream from the last stage heat reject evaporator and is returned to the tube bundle of the last stage in the recovery section. The combined stream is heated in the tubes and additional heating is provided in the brine heater using live steam. A portion of the flashing brine is discharged to waste from the last stage of the heat reject section. The product formed passes through all the stages in the plant and is stored or pumped to service from the last stage in the heat reject section.

The Point Loma unit had a total of 28 stages that include 26 stages for the heat recovery section and 2 stages for the heat reject section. GTMO No. 1 and No. 2 had a total of 15 stages each that include 12 stages for the heat recovery section and 3 stages for the heat reject section. Point Loma, GTMO No.1 and No.2 units were originally designed at a top temperature of 198 °F and a performance ratio (pound of product per 1,000 Btu) of 6.8 for Point Loma and 5.0 for GTMO No.1 and No.2. The concentration factor was limited to 1.5 between the brine blowdown and feed concentration. Due to corrosion to carbon steel vessel material, these units were rebuilt once. Because of water demand due to population growth, the unit inter-stage gates opening were redesigned to increase production by increasing the top brine temperature with acid treatment. With the increased of top brine temperature to 230°F, the production was able to be increased by 25 percent. These units were operated successfully for 24 years and were finally dismantled in 1988.

GTMO No. 3

GTMO No.3 is also a MSF unit but with once-through process. In the once-through process, raw seawater enters the cold end of the evaporator heat transfer tubing and is progressively heated in each stage. The seawater exits the hottest stage and passes through the brine heater, where it is heated to a temperature of 195°F with polymer treatment or 230°F when operating on acid. The hot brine is then admitted into the hottest stage flashing brine chamber. The flashed steam becomes the product as it condensed by seawater in the heat transfer tubing. The flashing brine is progressively exposed to lower pressures in each stage. At the lowest temperature stage, the brine chamber is at sub-atmospheric pressure. A pump is used to draw off the remaining brine from the last stage for discharge back to the sea. In this process, the brine concentration is only about 10% greater than the seawater supply. The advantage of the once through process over the recycle process is a more economical system to fabricate and lower brine concentration. The disadvantage is the increased chemical consumption. This unit had a total of 24 stages with a performance ratio of 8.0 pound of product per 1,000 Btu. This unit operated successfully for 14 years and was finally dismantled in 2002.

GTMO No.4 and No.5

GTMO No.4 and No. 5 are the multiple effect process with vapor thermo compression and falling film horizontal tube process. Raw seawater enters the first effect and is raised to the boiling point after being preheated in the tubes. The seawater is sprayed onto the surface of the top rows of evaporator tubes in a thin film to promote rapid boiling and evaporation. The tubes are heated by steam from a boiler that is condensed on the opposite side of the tubes. The condensate from the first effect is returned to the boiler for reuse. Only a portion of the seawater applied to the tubes in the first effect is evaporated. The remaining feed water is fed into the second effect, where it is again applied to the tubes bundle. These tubes are in turn being heated by the vapor created in the first effect. This vapor is then condensed to fresh water product, while giving up heat to evaporate a portion of the remaining seawater feed in the next effect. This continues for 13 effects. The remaining seawater from a group of effects is pumped to another group of effects. This unit was designed in 3 groups of effect and required 3 feed water pumps. The evaporator steel shell is coated with epoxy and the evaporator tubes are aluminum. Because of aluminum tubing, the top brine temperature can only be operating up to the maximum of 160°F. The performance ratio was designed at 12 pound per 1,000 Btu and the concentration factor is 1.9 between the concentrated brine and feed.

The units were successfully operated for 10 years. However, due to corrosion and scaling, these units were decommissioned in 2000.

Reverse Osmosis Desalination Units

The Reverse Osmosis (RO) desalination units in Guantanamo Bay include six units and each unit is equipped with energy recovery system. Power supply to these units is diesel generators. Table 2 shows the RO units installed in Guantanamo Bay.

	Year	Type	Manufacturer	Capacity
RO No. 1	1990	SWRO	Aqua Design	0.300 MGD
RO No. 2	1990	SWRO	Aqua Design	0.300 MGD
RO No. 3	2000	SWRO	Burns and Roe / Matrix	0.235 MGD
RO No. 4	2000	SWRO	Burns and Roe / Matrix	0.235 MGD
RO No. 5	2002	SWRO	Burns and Roe	0.235 MGD
RO No. 6	2003	SWRO	Brown and Root/Matrix	0.235 MGD

New Intake

The old intake for the thermal units and RO No. 1 and 2 was decommissioned in 2000. A new intake was installed to accommodate the new RO units and future expansion. Intake for RO No.1 and 2 was relocated to the new intake. Except for the material of construction, the new intake was essentially the same with the old intake that includes an offshore fish trap, a 24-inch diameter x 200-foot long high density polyethylene intake pipe, a chlorination system, an intake sump with traveling screen, and a pump structure. The intake pump supplies seawater to the header.

The seawater enters the fish trap or velocity cap and is chlorinated. The chlorination system is comprised of a gas feeder, vacuum regulator, ejector, booster pump, and polyethylene tubing. The chlorination system is located adjacent to the new intake structure. The fish trap is a flanged, 24-inch diameter tee attached to the seawater intake pipe elbow located about 25 feet below the water's surface. 1/8-inch wire mesh (1" x 1" hole) was welded all around the inside diameter of a stainless steel ring that is attached to both sides of the tee. The intake pipe is anchored with concrete supports every 15 feet. Upon entering the intake pump structure, the seawater then passes through a traveling screen and into the pump bays. Five intake pumps are provided to discharge the seawater into the header. Booster pumps distribute the seawater from the header to the dual media filter and respective RO trains.

Pretreatment Process

The seawater intake pumps supply the chlorinated seawater to the header, and the seawater booster pumps feed the chlorinated seawater from the intake to the dual-media filters for removal of suspended solids. Before entering the manual dual media filters, coagulant is added to the chlorinated seawater to aid in coagulating the fine particles and colloidal materials. This material is then filtered out in the filter.

Sodium bisulfite, sulfuric acid, and anti-scalant are added to the dual media effluent before it enters the cartridge filter to further remove any suspended material. The addition of sodium bisulfite is to remove the residual chlorine and any oxidizing agents in the pretreated seawater. Sodium bisulfite also acts as a disinfectant by inhibiting the growth of algae and other organisms that would foul and deteriorate the RO membrane. The sulfuric acid is added to remove the bicarbonate so that the RO system can be operated at a 40% recovery rate. Sulfuric acid is automatically controlled via a

4-20-milliamp (mA) signal from the pH controller. The anti-scalant is added to inhibit the precipitation of calcium sulfate in the RO membrane.

Desalination Process

After leaving the cartridge filter, the effluent will be put in a bypass mode and drained. The effluent will then be checked to assure the quality of the treated seawater is within the RO feedwater requirements before entering the RO high-pressure pump. The RO feedwater requirements are as follows:

Silt Density Index (SDI) (15 minutes)	< 4.0
Turbidity (NTU)	< 1.0
Organic material	Absent
Active oxidizing agents	Nil
Combined Fe and Mn	< 0.10 milligrams per liter (mg/L)
Grease and oil	Nil
Suspended Solids	< 7.0 mg/L
Temperature	70 - 85°F
pH	6.8

The treated seawater enters the RO high-pressure pump intake manifold, and from there it is pumped at a pressure between 800 and 1,000 psig depending upon the age and condition of the RO membranes and the quality of the product water. The RO product water is collected in a common manifold and then pumped into the degasifier to remove carbon dioxide. Before discharging back into the sea, the high-pressure reject brine flows into an energy recovery system and a backwash tank. The energy recovery system is connected to the RO high-pressure pump to reduce the RO system’s overall power consumption. Due to different contractors and designers, the high-pressure pump and energy recovery system are different for some of the RO units.

The Aqua Design RO No.1 and RO No. 2 units include a horizontal, multiple stage, centrifugal, high-pressure pump and energy recovery turbine system is shown in Figure 1.

The Burns and Roe/Matrix RO No.3, RO No.4 and Burns and Roe RO No.5 units include a positive displacement, high-pressure pump and hydraulic turbocharger energy recovery system is shown in Figure 2.

The Brown and Root/Matrix RO No.6 unit includes a positive displacement, high pressure pump and hydraulic turbocharger energy recovery system. The energy recovery system was up-graded by Burns and Roe to a pressure exchanger energy recovery system and is shown in Figure 3.

Water Stabilization and Distribution

The water stabilization system was originally designed for the very low TDS of the thermal desalination system. Due to piping arrangement, the existing stabilization system is continuously used to post treat the RO product water.

After degasification of the RO product to remove carbon dioxide, the degasified RO product water is treated with chlorine before it is pumped through a lime bed where lime is added to raise the pH. Sodium hexametaphosphate (SHMP) is then added to the lime-treated product water for

distribution piping protection before the water enters a holding tank. From the holding tank, the water is transferred to a clarifier for pH adjustment with hydrated lime. The effluent from the clarifier goes into a recarbonation tank where carbon dioxide from a submerged propane burner is added to neutralize the excess lime and to precipitate it as calcium carbonate. Prior to entering the sand filters, SHMP and fluoride are added for piping protection and to reduce dental cavities in the Base's population. The effluent from the filters goes into a clearwell where chlorine is added and then the effluent is pumped into the water distribution tanks. The water distribution tanks are located at about 500 feet elevation. The water is distributed by gravity to the Base and the final water composition is maintained as shown in Table 3.

PH	8.5
Conductivity, $\mu\text{S}/\text{cm}$	612
Total Dissolved Solids (TDS), ppm	337
Chloride, ppm	160
Total Hardness, ppm CaCO_3	55
Calcium Hardness, ppm CaCO_3	46
Dissolved Oxygen, ppm	7.2
OH – Alkalinity, ppm CaCO_3	0
P - Alkalinity, ppm CaCO_3	2
T – Alkalinity, ppm CaCO_3	46
Carbonate, ppm CaCO_3	4
Bicarbonate, ppm CaCO_3	42
Chlorine (Residual), ppm	1.20
T – Phosphate, ppm PO_4	2.11
O – Phosphate, ppm PO_4	1.02
Fluoride, ppm	0.60
Turbidity, NTU	0.80
Fe, ppm	0.01
Cu, ppm	Below Detection
Langelier Saturation Index (LSI)	0.15
Ryznar Stability Index	8.29
Sulfate, ppm	1.0
Temperature, °F	83

Figure 4 shows the flow diagram of the product water stabilization prior to distribution by gravity flow to the whole Base.

Operating Criteria

Aside from the normal Standard Operating Procedures for start-up, normal operation, and shutdown, the following are some of the criteria used in order to minimize membrane fouling, membrane degradation, and to maintain product flow and quality. These criteria are based on the experience from operating the thermal units and RO No.1 and RO No.2 units.

1. Chemical dosages:
 - Chlorine – seawater intake 0.6 to 0.8 mg/L
 - Coagulant – Raw seawater feed to filter 1.0 to 5.0 mg/L
 - Sulfuric acid – to maintain RO feed pH between 6.7 – 7.0 mg/L
 - Sodium bisulfite – 4 mg/L
 - Anti-scalant between 2 .0 -2.5 mg/L

2. Dual media filter backwash frequencies - each media filter is backwashed once everyday for 30 minutes.
3. Maintain design RO product flow at 40% recovery.
4. Maintain RO feed pressure lower than maximum design.
5. Maintain RO product conductivity lower than maximum design.
6. Membrane cleaning frequencies – each RO unit is cleaned every three months. The cleaning is conducted with a high pH detergent solution and/or citric acid for a few hours to normalize the differential pressure across the membrane.
7. Seawater intake cleaning frequencies - the intake sump and traveling screen are cleaned every three months to remove accumulated silt and fine sand.
8. Membrane flushing frequencies – each RO unit is flushed with product water for 5 to 10 minutes after every shutdown. If the RO unit remains out of service for up to two weeks, the unit is flushed every 48 hours. For longer periods of shutdown, the unit is preserved with sodium bisulfite solution and the solution is replaced every 30 days.

Operating Experience

The Guantanamo Bay Aqua Design seawater RO units have been operating since 1990 while all other units started operation between 2000 and 2003. Overall, the operation of the seawater RO desalination units has been very successful and continues to provide quality potable water to the Naval Base.

1. Product flows – have remained constant at design capacity over the years and no significant changes have been noticed.
2. Product quality– lower than the maximum allowable TDS at 450 mg/L.
Aqua Design RO1 and RO2 – 200 to 325 mg/L
Burns and Roe Matrix RO3 and RO4 – 125 to 275 mg/L
BRSC RO5 – 100 to 125 mg/L
Burns and Roe Matrix RO6 – 125 to 175 mg/L
3. RO feed pressure – within design feed pressure.
Aqua Design RO1 and RO2 – 900 to 920 psig
BRSC/Matrix RO3 and RO4 – 840 to 870 psig
BRSC RO5 – 870 to 900 psig
Burns and Roe/Matrix RO6– 850 to 870 psig
4. Membrane replacement – Very few membrane failures have been experienced. However, in order to keep the overall product of each unit within the allowable TDS, membranes are probed whenever the unit overall product TDS is between 300 and 350 mg/L. The membrane is replaced when the TDS reaches 400 mg/L. Over the years, a few membranes are replaced every year on each unit.
5. Filter media replacement. In 1999, the Aqua Design RO1 and RO2 filter media were replaced due to the failure of the bottom distribution piping that permitted a large quantity of sand into the cartridge filters.
In 2003, the Aqua Design RO1 and RO2 filter media were replaced again due to filter vessel leak from corrosion.
No filter media have been replaced on any other units.

6. Equipment replacement.
The Aqua Design RO2 high-pressure pump reduction gear failed once and was replaced. The high-pressure pump motor has failed several times.
7. Cartridge filter.
The cartridge filter elements are normally replaced every four months.
8. Corrosion.
In 2003, the Aqua Design RO1 and RO2 filter media vessels were corroded beyond repair and were replaced.
Minor corrosion also occurred on the supporting structures for the RO pressure vessels, media filters, and cartridge filters. All these supporting structures are now repaired and repainted once a year.
9. Scheduled outage.
Scheduled outage for all units:
Clean intake sump and traveling screens.
Shock chlorine dosage for the intake and filter media.
Scheduled outage for one RO unit at a time:
Replace cartridge filter elements.
Repair minor leaks on polyvinyl chloride (PVC) pipes.
10. Unscheduled outage.
Unscheduled outage is normally due to power failure. The Base normally experiences one to ten power outages each year
11. Power consumption.
Aqua Design's RO1 and RO2 with centrifugal multistage pump and energy recovery turbine – 16.5 kwh/1,000 gallon.
Burns and Roe/Matrix RO3 and RO4 and Burns and Roe upgrade with positive displacement pump and hydraulic turbocharger energy recovery – 13.6 kwh/1,000 gallons.
Burns and Roe RO5 with positive displacement pump and hydraulic turbocharger energy recovery – 13.5 kwh/1,000 gallons.
Burns and Roe RO6 upgrade with positive displacement pump and pressure exchanger energy recovery – 9.7 kwh/1,000 gallons.

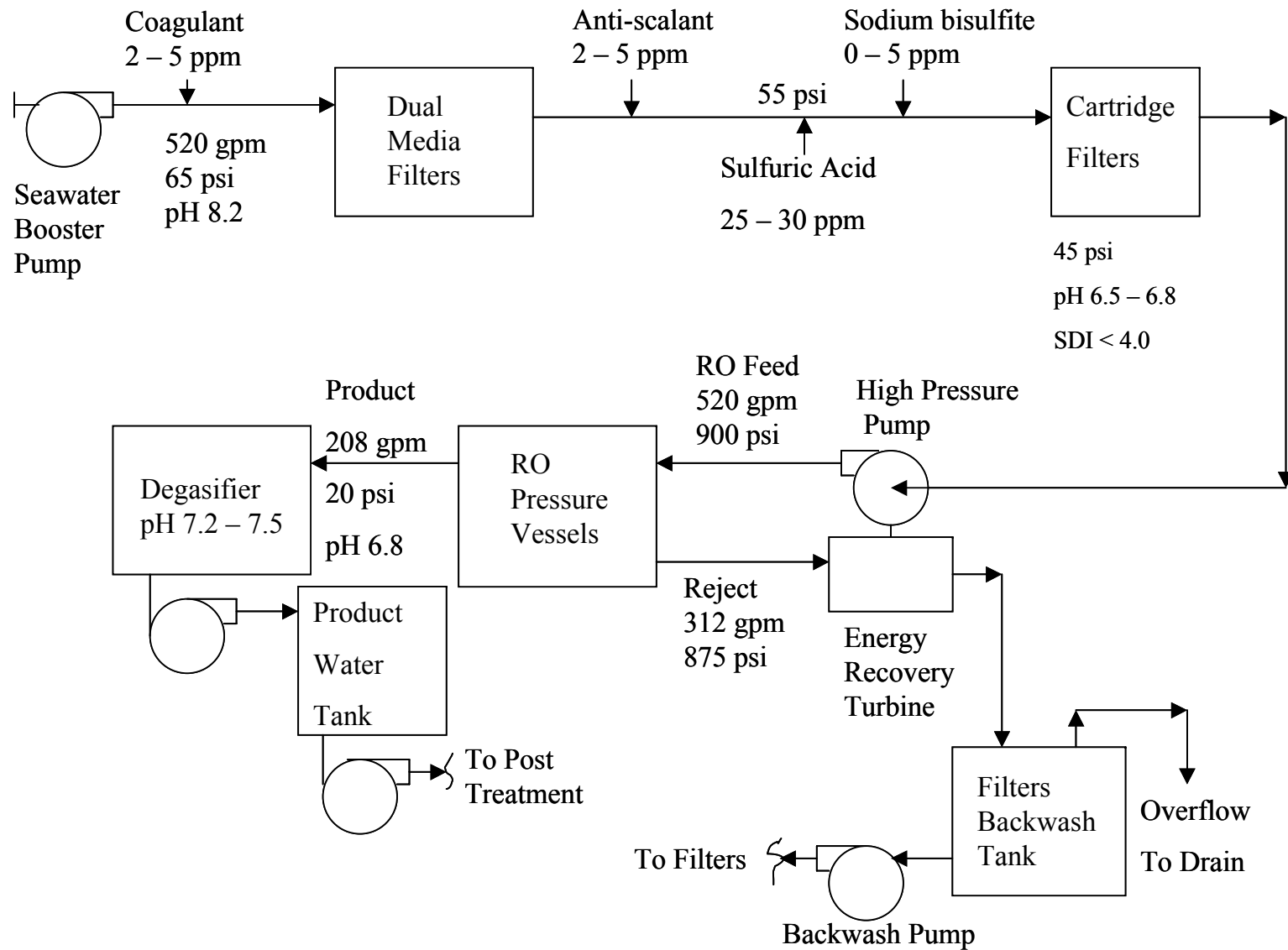


Figure 1. GTMO SWRO Desalination Plant Typical Flow Diagram With Energy Recovery Turbine

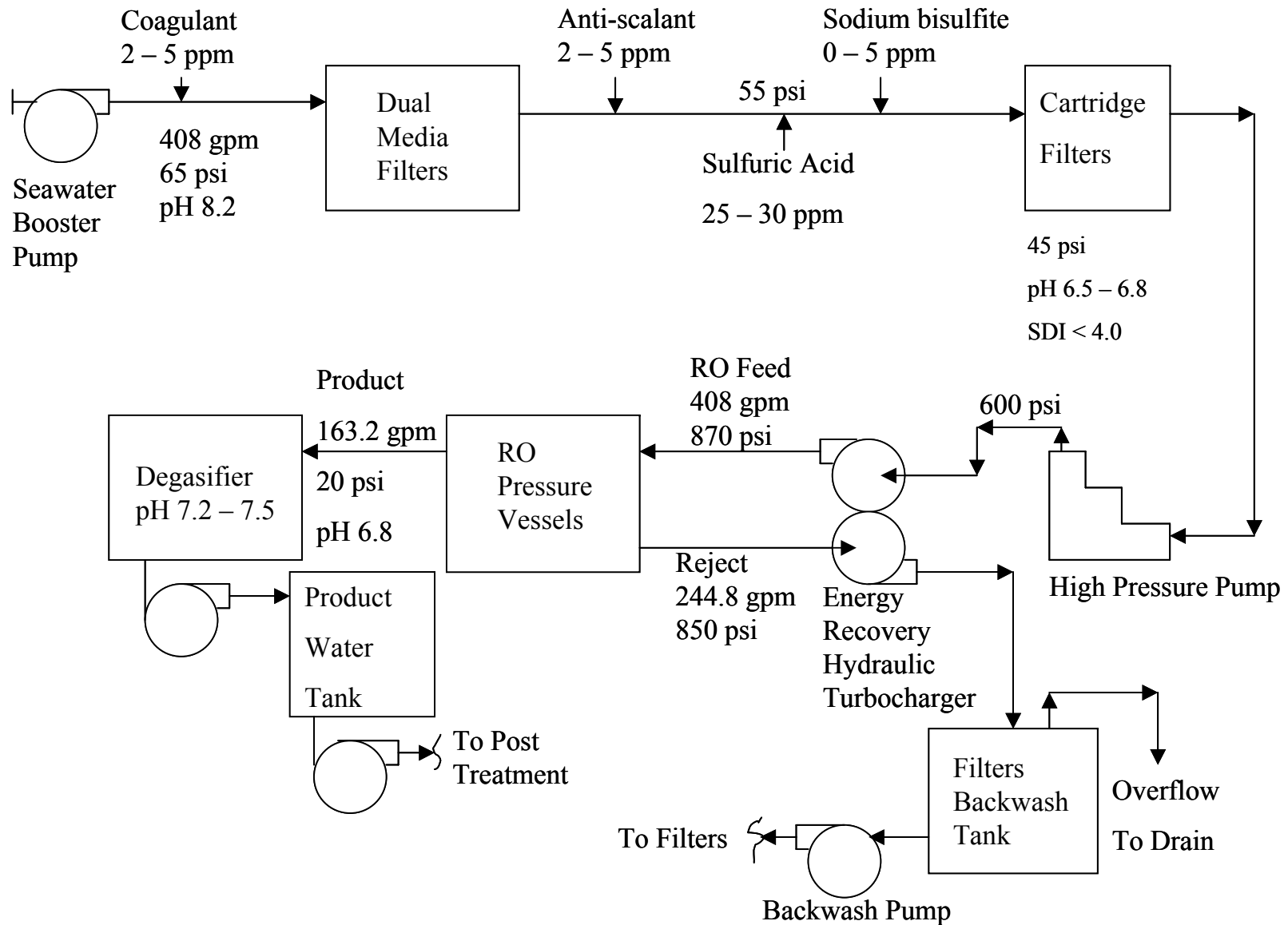


Figure 2. GTMO SWRO Desalination Plant Typical Flow Diagram With Hydraulic Turbocharger Energy Recovery.

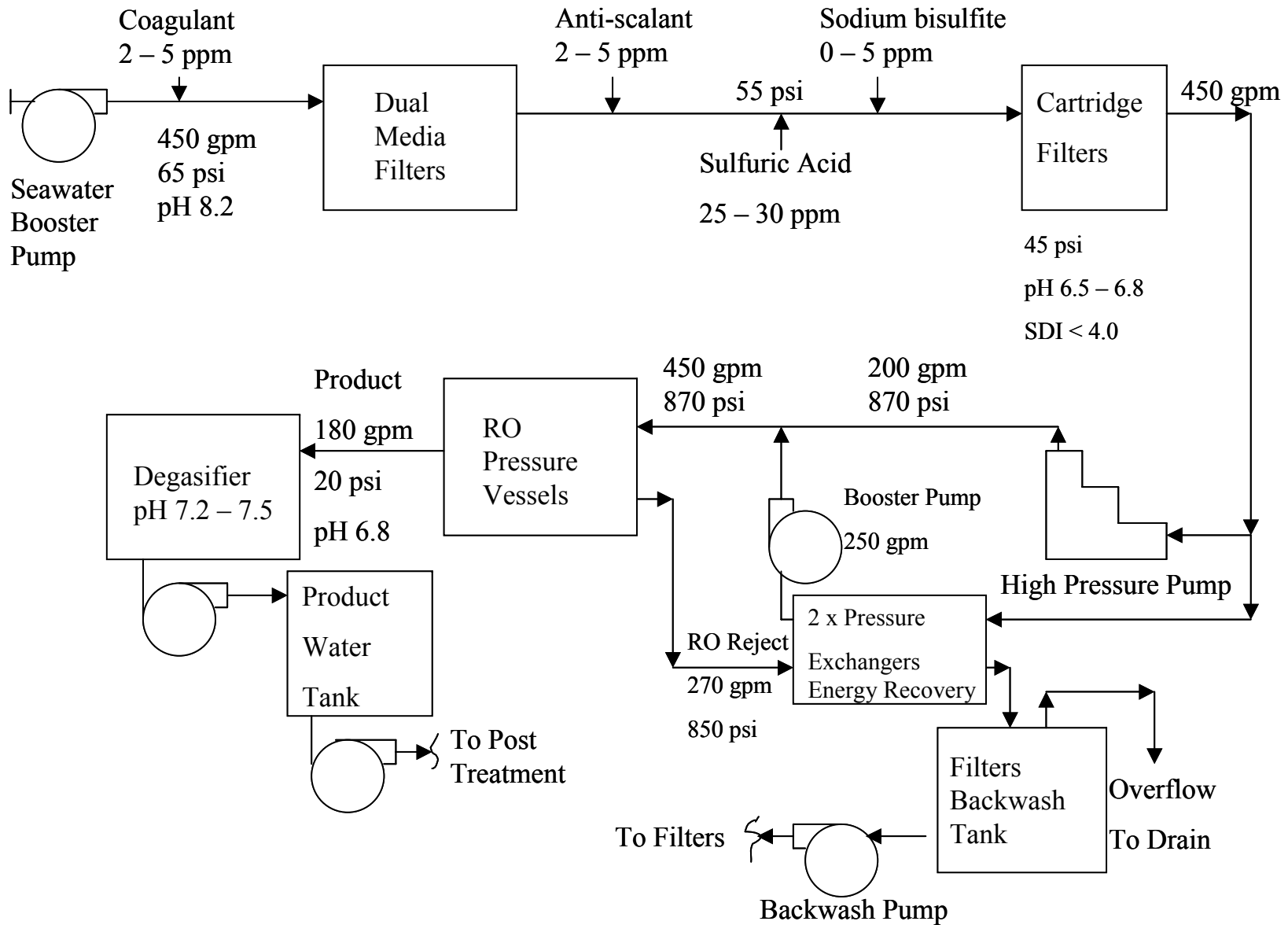


Figure 3. GTMO SWRO Desalination Plant Typical Flow Diagram With Pressure Exchanger Energy Recovery.

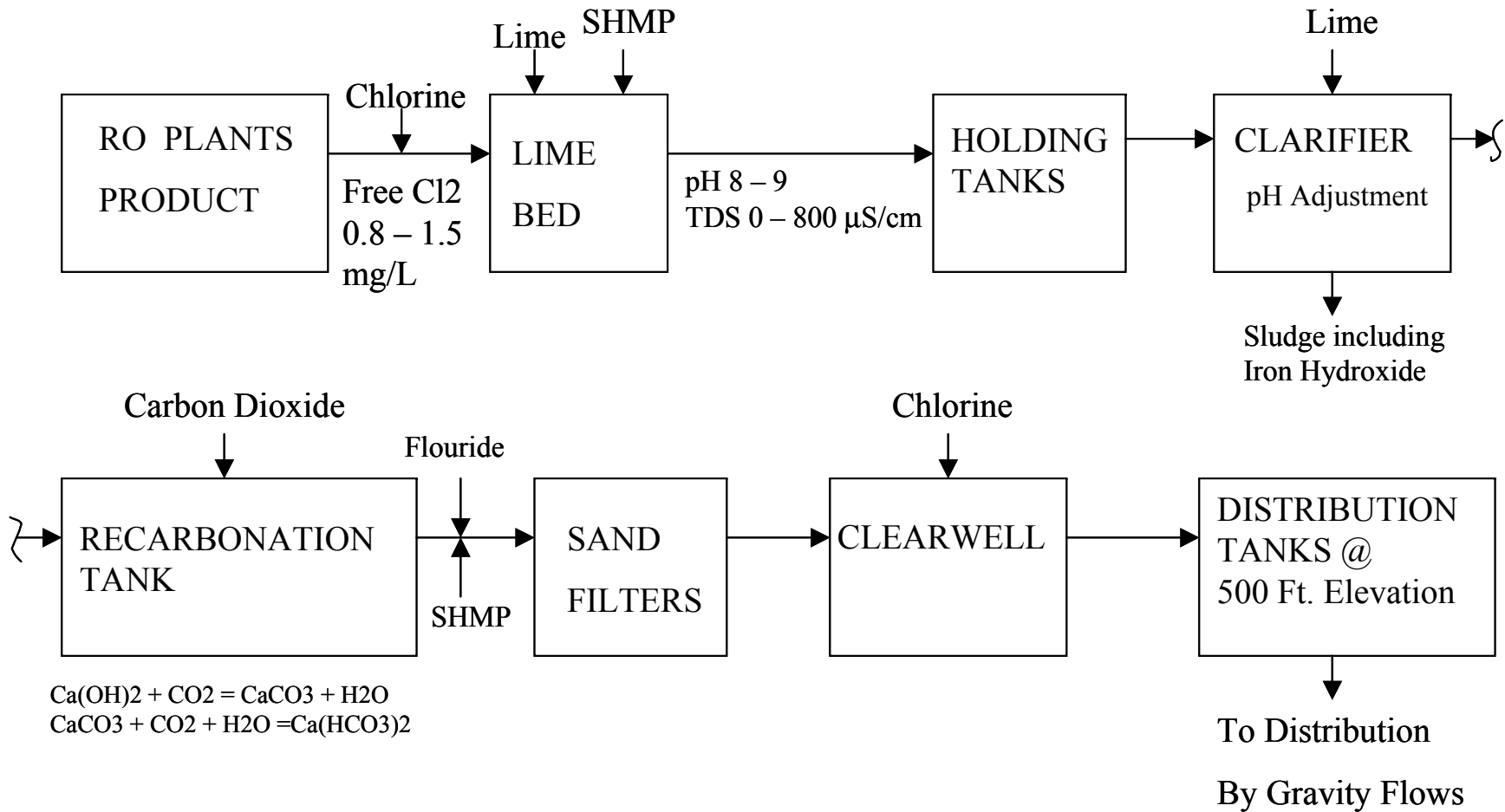


Figure 4. GTMO Post Treatment Flow Diagram